# APPENDIX 19D EQUIPMENT SURVIVABILITY ASSESSMENT

## 19D.1 Introduction

The purpose of the equipment survivability assessment is to evaluate the availability of equipment and instrumentation used during a severe accident to achieve a controlled, stable state after core damage under the unique containment environments. Severe accident phenomena may create harsh, high temperature and pressure containment environments with a significant concentration of combustible gases. Local or global burning of the gases may occur, presenting additional challenges to the equipment. Analyses demonstrate that there is reasonable assurance that equipment used to mitigate and monitor severe accident progression is available at the time it is called upon to perform.

The methodology used to demonstrate equipment survivability is:

- Identify the high level actions used to achieve a controlled, stable state
- Define the accident time frames for each high level action
- Determine the equipment and instruments used to diagnose, perform and verify high level actions in each time frame
- Determine the bounding environment within each time frame
- Demonstrate reasonable assurance that the equipment will survive to perform its function within the severe environment.

## 19D.2 Applicable Regulations and Criteria

Equipment that is classified as safety-related must perform its function within the environmental conditions associated with design-bases accidents. The level of assurance provided by equipment required for design-bases events is “equipment qualification.”

The environmental conditions resulting from beyond design basis events may be more limiting than conditions from design-bases events. The NRC has established criteria to provide a reasonable level of assurance that necessary equipment will function in the severe accident environment within the time span it is required. This criterion is referred to as “equipment survivability.”

The applicable criteria for equipment, both mechanical and electrical, required for recovery from in-vessel severe accidents are provided in 10 CFR 50.34(f):

- Part 50.34(f)(2)(ix)(c) states that equipment necessary for achieving and maintaining safe shutdown of the plant and maintaining containment integrity will perform its safety function during and after being exposed to the environmental conditions attendant with the release of hydrogen generated by the equivalent of a 100 percent fuel-clad metal-water reaction including the environmental conditions created by activation of the hydrogen control system.

- Part 50.34(f)(2)(xvii) requires instrumentation to measure containment pressure, containment water level, containment hydrogen concentration, containment radiation intensity, and noble gas effluent.

- Part 50.34(f)(2)(xix) requires instrumentation adequate for monitoring plant conditions following an accident that includes core damage.

- Part 50.44(c)(2) states that systems necessary to ensure containment integrity shall be demonstrated to perform their function under conditions associated with an accident that releases hydrogen generated from 100-percent fuel-clad metal-water reaction.

Part 50.44(c)(4) states that equipment must be provided for monitoring hydrogen in the containment that is functional, reliable, and capable of continuously measuring the concentration of hydrogen in the containment atmosphere following a significant beyond design-basis accident for accident management, including emergency planning. The applicable criteria for equipment, both electrical and mechanical, required to mitigate the consequences of ex-vessel severe accidents are discussed in Section III.F, "Equipment Survivability" of SECY-90-016. The NRC recommends in SECY-93-087 that equipment provided only for severe accident protection need not be subject to 10 CFR 50.49 equipment qualification requirements, the 10 CFR 50 Appendix B quality assurance requirements, or 10 CFR 50 Appendix A redundancy/diversity requirements. However, mitigation features must be designed to provide reasonable assurance they will operate in the severe accident environment for which they are intended and over the time span for which they are needed.

## 19D.3 Definition of Controlled, Stable State

The goal of accident management is to achieve a controlled, stable state following a beyond design basis accident. Establishment of a controlled, stable state protects the integrity of the containment pressure boundary. The conditions for a controlled, stable state are defined by APP-GW-GL-027, the "Framework for AP1000 Severe Accident Management Guidance" (SAMG) (Reference 19D-1).

For a controlled, stable core state:

- A process must be in place for transferring the energy being generated in the core to a long-term heat sink.

- The bulk core temperature must be well below the point where chemical or physical changes might occur.

For a controlled, stable containment state:

- A process must be in place for transferring the energy that is released to the containment to a long-term heat sink.

- The containment boundary must be protected.

- The containment and reactor coolant system conditions must be well below the point where chemical or physical processes (severe accident phenomena) might result in a dynamic change in containment conditions or a failure of the containment boundary.

## 19D.4 Definition of Equipment Survivability Time Frames

The purpose of the equipment survivability time frames is to identify the time span in the severe accident in which specific equipment is required to perform its function. The phenomena and environment associated with that phase of the accident defines the environment which challenges the equipment survivability. The equipment survivability time frame definitions are summarized in Table 19D-1.

### 19D.4.1 Time Frame 0 - Pre-Core Uncovery

Time Frame 0 is defined as the period of time in the accident sequence after the accident initiation and prior to core uncovery. The fuel rods are cooled by the water/steam mixture in the reactor vessel. The accident has not yet progressed beyond the design basis of the plant, and hydrogen generation and the release of fission products from the core is negligible. Emergency Operating Procedures (EOPs) are designed to maintain or recover the borated water inventory and heat removal in the reactor coolant system to prevent core uncovery and establish a safe, stable state. Recovery within Time Frame 0 prevents the accident from becoming a severe accident. Equipment survivability in Time Frame 0 is covered under the design basis equipment qualification program for the primary accident management strategies.

### 19D.4.2 Time Frame 1 - Core Heatup

Time Frame 1 is defined as the period of time after core uncovery and prior to the onset of significant core damage as evidenced by the rapid zirconium-water reactions in the core. This is the transition period from design basis to severe accident environment. The overall core geometry is intact and the uncovered portion of the core is overheating due to the lack of decay heat removal. Hydrogen releases are limited to relatively minor cladding oxidation and some noble gas and volatile fission products may be released from the fuel-clad gap due to rupture of fuel rod cladding at these higher temperatures. As the core-exit gas temperature increases above 1200 degrees F, the EOPs transition to a red path indicating inadequate core cooling (FR-C.1). Upon entry into FR-C.1, the control room staff initiates actions to mitigate a severe accident by turning on the hydrogen igniters for hydrogen control and flooding the reactor cavity to prevent reactor pressure vessel failure. The operators attempt to reduce the core temperature by depressurizing the RCS and re-establish the borated water inventory in the reactor coolant system. Recovery in Time Frame 1 prevents the accident from becoming a core melt. In general, the containment conditions are expected to be within the design basis conditions while the reactor vessel and RCS conditions will be slightly above the design basis. Equipment survivability in Time Frame 1 is evaluated to demonstrate it is within the equipment qualification envelope except for components inside the RCS pressure boundary.

### 19D.4.3 Time Frame 2 - In-Vessel Severe Accident Phase

Time Frame 2 is the period of time in the severe accident after the accident progresses beyond the onset of rapid zirconium-water reactions and prior to the establishment of a controlled, stable state (end of in-vessel core relocation), or prior to reactor vessel failure. The onset of rapid zirconium-water reactions of the fuel rod cladding and hydrogen generation defines the beginning of Time Frame 2. The heat of the exothermic reaction accelerates the degradation, melting and relocation of the core. Fission products are released from the fuel-clad gap as the cladding bursts and from the fuel matrix as the $UO_2$ pellets melt. Over the period of Time Frame 2, the initial, intact geometry of the core is lost as it melts and relocates downward. Severe accident management strategies exercised during Time Frame 2 are designed to recover reactor coolant system inventory and heat removal, to maintain reactor vessel integrity and to maintain containment integrity. Recovery actions in Time Frame 2 may create containment environmental challenges by increasing the rate of hydrogen and steam generation.

### 19D.4.4 Time Frame 3 - Ex-Vessel Severe Accident Phase

Time Frame 3 is defined as the period of time after the reactor vessel fails until the establishment of a controlled, stable state. The AP1000 design and the AP1000 EOPs provide the capability to flood the reactor vessel and depressurize the RCS to prevent vessel failure in a severe accident. This severe accident Time Frame 3 is predicted to be a very low probability event. However, it is included in the SAMG to provide guidance in the event that reactor vessel failure occurs. Molten core debris is relocated from the reactor vessel onto the containment cavity floor which creates the potential for rapid steam generation, core-concrete interaction and non-condensable gas generation. Severe accident management strategies implemented in Time Frame 3 are designed to monitor the accident progression, attempt to re-establish a coolable core configuration on the containment floor, maintain containment integrity and mitigate fission product releases to the environment.

## 19D.5 Definition of Active Operation Time

Equipment only needs to survive long enough to perform its function to protect the containment fission product boundary. In the case of some items, such as valves or motor-operators, once the equipment performs its function, and changes state (e.g., opens), the function is completed. An exception to this is solenoid-operated valves that must maintain a position other than their design basis failure position (e.g., a fail closed AOV that must remain open for a strategy to remain effective). For other items, such as pumps, the equipment must operate continuously to perform its function. The time of active operation is the time during which the equipment must perform its function.

## 19D.6 Equipment and Instrumentation for Severe Accident Management

The AP1000 EOPs (Reference 19D-2) and severe accident management guidance (SAMG) framework (Reference 19D-1) define actions that accomplish the goals for achieving a controlled, stable state and terminating fission product releases in an accident. The high level actions from the accident management framework are summarized in Table 19D-2 and provide the basis for identifying equipment. This section discusses the EOP and SAMG actions within each of the time frames of the accident to determine the equipment and instrumentation and the active operation time in which they are needed to provide reasonable assurance of achieving a controlled, stable state.

The AP1000 SAMG (Reference 19D-3) provides the primary input to the selection of the instrumentation used for monitoring the actions. The instrument used to diagnose the need for the action and monitor the response are listed. Instruments to evaluate potential negative impacts are covered under other high level actions in the framework and therefore are also considered for survivability.

The equipment and instrumentation used in each time frame are summarized in Tables 19D-3 through 19D-5. Although the SAMG considers all possible paths for each high level action, only the primary method is listed in Tables 19D-4 and 19D-5 for the equipment survivability assessment.

### 19D.6.1 Time Frames 0 and 1 - Accident Initiation, Core Uncovery and Heatup

Time Frame 0 represents the accident time prior to core uncovery. Time Frame 1 represents the time following core uncovery, but prior to the rapid oxidation of the core. Aside from potential ballooning of the cladding, the core has not lost its initial intact geometry and coolability is assured by recovering the core with borated water.

During Time Frames 0 and 1, most of the equipment that is automatically actuated will receive a signal to start. However, given that the accident has progressed to core uncovery and heatup, some critical equipment has not actuated. From accident initiation until the time of core uncovery (Time Frame 0) the conditions are bounded by the design basis and covered under equipment qualification. During Time Frame 1, the containment environment is still within the design basis of the plant and the control room is operating within the Emergency Operating Procedures, but the conditions have degraded. Accident management to achieve a controlled, stable state, via the EOPs, is geared toward recovering the core cooling before the coolable geometry is lost.

#### 19D.6.1.1 Injection into the RCS

Failure of RCS injection is likely to be the reason the accident has proceeded to core uncovery. Successful injection into the RCS removes the sensible and decay heat from the core. Prior to the onset of rapid oxidation of the cladding, successful RCS injection recovers the accident before it progresses to substantial damage and establishes a controlled, stable state. Failure to inject into the RCS at a sufficient rate allows the accident to proceed into Time Frame 2 and the SAMG.

The equipment and systems used to inject into the RCS during Time Frame 0 and 1 are the core makeup tanks, accumulators and IRWST (which are part of the passive core cooling system (PXS)), the chemical and volume control system (CVS) makeup pumps, and the normal residual heat removal (RNS) pumps. For non-LOCA and small LOCA sequences, depressurization of the RCS using the automatic depressurization system (ADS) is required for successful injection.

The plant response is monitored using the system flow rates, IRWST water level indication, RCS pressure, core-exit temperature, and RCS temperature.

#### 19D.6.1.2 Injection into Containment

The operator is instructed via the EOPs to inject water into the containment to submerge the reactor vessel and cool the external surface if core overheating begins to occur. This action is performed later in Time Frame 1, but prior to entry into the SAMG. Successful cavity flooding, in conjunction with RCS depressurization, prevents vessel failure in the event of molten core relocation to the vessel lower head. Failure of cavity flooding allows the accident to proceed to vessel failure and molten core relocation into the containment (Time Frame 3) if timely injection into the reactor vessel cannot be established to cool the core and prevent substantial core relocation to the lower head.

The PXS motor-operated and squib recirculation valves are opened manually to drain the IRWST water into the containment in Time Frame 1.

The plant response is monitored by core-exit temperature, containment water level indication, and IRWST water level indication.

#### 19D.6.1.3 Decay Heat Removal and Injection into the Steam Generators

In the event of non-LOCA or small LOCA sequences, the RCS pressure is elevated above the secondary pressure. In Time Frame 0, the SGs and PRHR are used for decay heat removal. Note that PRHR is effective only in Time Frame 0. Failure of the PRHR may be the reason that the event proceeds to core overheating. Recovery of the PRHR will provide decay heat removal. Failure of feedwater to the steam generators with the PRHR failed may also be a cause for core overheating and recovery of injection to the steam generators may be required. If the steam generators remain dry without PRHR recovery and the core is uncovered, the tube integrity or hot leg nozzle integrity may be threatened by creep rupture failure at the onset of rapid oxidation (entry into Time Frame 2) if the RCS is at a high pressure. Injecting to the steam generators provides a heat sink to the RCS by boiling water on the secondary side, and protects the tubes by cooling them. Successful steam generator injection can establish a controlled, stable state if the losses from the RCS can be recovered and mitigated. Failure to inject to the steam generator requires depressurization of the RCS to prevent creep rupture failure of the tubes and loss of the containment integrity at the onset of rapid oxidation in Time Frame 2.

For accident sequences initiated by steam generator tube rupture, the procedures instruct the control room to isolate feedwater to the faulted steam generator, and to use feedwater to the intact steam generator in conjunction with steam generator depressurization and PRHR initiation to cooldown the reactor coolant system and isolate the break. In Time Frame 1, PRHR initiation or feed to the intact steam generators may be used to re-establish a primary heat sink to cooldown the RCS and a controlled, stable state if the losses from the RCS can be recovered and mitigated. Failure to recover the PRHR or to feed the intact steam generator may lead to a continued loss of coolant to the faulted steam generator and progression to Time Frame 2.

The main feedwater and startup feedwater pumps are used to inject into a pressurized secondary system. The AP1000 plant design does not allow for use of low pressure systems (e.g., condensate, fire water, or service water) to feed the steam generators.

The plant response is monitored with the steam generator water level indication, steam line pressure, core-exit temperature, RCS temperature, IRWST temperature, and IRWST water level indication.

### 19D.6.1.4 Depressurize Reactor Coolant System

#### 19D.6.1.4.1 Non-LOCA and Small LOCA Sequences

In Time Frame 0, RCS depressurization is not used for most accidents because the steam generators and PRHR are used to establish a controlled stable state.

In the event of non-LOCA or a small LOCA sequences, the RCS pressure will remain above the secondary pressure. If the steam generators are dry and the core is uncovered, the hot leg nozzle or tube integrity is threatened by creep rupture failure at the onset of rapid cladding oxidation (beginning of Time Frame 2). Timely depressurization (prior to significant cladding oxidation) of the RCS mitigates the threat to the tubes, allows injection of the accumulators and IRWST water, and provides a long-term heat sink to establish a controlled, stable state. Failure to depressurize can result in the failure of the tubes and a loss of containment integrity when oxidation begins.

For steam generator tube rupture (SGTR) initiated sequences, depressurization of the RCS can be used to isolate the faulted steam generator, and re-establish core cooling via injection.

The automatic depressurization system (ADS) is required to depressurize the RCS to allow the PXS systems to inject. However, the recovery of passive residual heat removal (PRHR) or feedwater to the steam generators will provide a substantial heat sink to depressurize the RCS and mitigate the threat to the tubes. The auxiliary pressurizer sprays are not evaluated for survivability since the inclusion of several other safety-related systems which perform the same function provides reasonable assurance of RCS depressurization in the event of a non-LOCA or small LOCA severe accident.

The RCS pressure, steam generator pressure, IRWST water level, and IRWST temperature can be used to monitor the plant response to the RCS depressurization.

#### 19D.6.1.4.2 LOCA Sequences

In Time Frame 0, steam generators and PRHR are not effective due to low RCS pressure.

LOCA sequences (other than small LOCA sequences) by definition are depressurized below the secondary system pressure by the initiating event and therefore, are not a threat to steam generator tube integrity upon the onset of rapid oxidation. Depressurization may be required for injection to establish a long-term heat sink. Medium LOCAs require additional depressurization to allow the injection of RNS or PXS. Large LOCAs are fully depressurized by the initiating event.

In LOCA sequences, the ADS is effective in providing depressurization capability to allow injection to the RCS. While RCS cooldown and depressurization using the steam generators could be effective, it is not evaluated here for survivability for LOCA sequences. RCS cooldown using pressurizer sprays was determined to not be effective for the larger LOCA sequences because of the loss of communication between the RCS and the pressurizer for these sequences.

The RCS pressure can be used to monitor the plant response to the RCS depressurization.

#### 19D.6.1.4.3 Prevent Reactor Vessel Failure

Depressurization of the RCS, along with injecting into the containment is an accident management strategy to prevent vessel failure. The depressurization of the RCS reduces the stresses on the damaged vessel wall facilitating the in-vessel retention of core debris. To prevent reactor vessel failure, the RCS must be depressurized to nearly containment conditions.

The ADS is used to depressurize the RCS to prevent reactor vessel failure. The use of the steam generators to depressurize the RCS to prevent vessel failure was determined to not be effective because it cannot bring the RCS pressure down far enough in the time frame of interest for accidents that progress to Time Frame 1 (i.e., no water on primary side of steam generators).

The RCS pressure can be used to monitor the plant response to the RCS depressurization.

### 19D.6.1.5 Depressurize Steam Generators

The steam generators may be depressurized to depressurize the RCS in non-LOCA and small LOCA sequences. Injection to the steam generator must be available to depressurize the secondary system to prevent creep rupture failure of the tubes.

The steam generator PORV and main steam bypass valves are used for depressurizing the steam generators. The MSIV must be opened in order to use the main steam bypass valves.

Depressurization of the steam generators is used in the EOPs as a means to cool down and depressurize the RCS. Depressurization of the steam generators is called for in the EOPs and is appropriate only in Time Frame 1 as the RCS is depressurized in order to minimize the pressure differential across the steam generator tubes.

The steam line pressure, steam generator water level, and RCS pressure can be used to monitor the plant response.

### 19D.6.1.6 Containment Heat Removal

Containment heat removal is not explicitly listed as a high level action in the AP1000 SAMG Framework, but it is implicit in the high level action “Depressurize Containment.” Containment heat removal is provided by the passive containment cooling system (PCS). Water cooling of the shell is needed to establish a controlled, stable state with the containment depressurized. The actuation of PCS water is typically automatic in Time Frame 0.

PCS water is supplied to the external surface of the containment shell from the PCS water storage tank or the post-72 hour PCS ancillary water tank. Alternative water sources can be provided via separate connections outside containment.

The containment heat removal can be monitored with the containment pressure and the PCS water flowrate or PCS water and PCS ancillary water storage tank levels.

### 19D.6.1.7 Containment Isolation

Containment isolation is not explicitly listed as a high level action in the AP1000 SAMG Framework, but it is implicit as a requirement to protect the fission product barrier.

Containment isolation is provided by an intact containment shell and the containment isolation system which closes the isolation valve in lines penetrating the containment shell that may be open to either the RCS or containment atmosphere following an accident.

The containment isolation can be monitored by the containment pressure and the containment isolation system valve positions.

### 19D.6.1.8 Hydrogen Control

Maintaining the containment hydrogen concentration below a globally flammable limit is a requirement for a controlled, stable state. The containment can withstand the pressurization from a global deflagration. While hydrogen is not generated in a significant quantity until Time Frame 2, provisions are provided in the EOPs within Time Frame 1 to turn on the hydrogen igniters before hydrogen generation begins so that hydrogen can be burned as it is produced.

Severe accident hydrogen control in the AP1000 is provided by hydrogen igniters. The containment has passive auto-catalytic recombiners (PARs) as well, but they are not credited in the severe accidents assessments. The PARs are passive equipment that cannot be controlled by the operating staff from the control room.

The igniters are manually actuated from the control room in the EOPs on high core-exit temperature. The intention is to actuate the igniters prior to the onset of significant cladding oxidation (Time Frame 1). The containment hydrogen concentration is monitored prior to igniter actuation so that a globally flammable mixture is not unintentionally ignited by the hydrogen igniters.

The plant response to the igniter actuation can be monitored by containment hydrogen concentration using the hydrogen monitors or containment atmosphere sampling, which is part of the primary sampling system. The containment pressure response can also be used to indicate hydrogen burning, which creates a distinctive pressure global peak, but not continual hydrogen burning by the igniters because the energy release to containment is at a low rate and the containment pressure response cannot be distinguished from other heat generation processes.

### 19D.6.1.9 Accident Monitoring

Accident monitoring is a post-TMI requirement as outlined in 10 CFR 50.34(f). Aside from the accident management purposes outlined above, monitoring the progression of the accident and radioactive releases provides input to emergency response and emergency action levels.

Accident monitoring is provided by the in-containment monitors for pressure, hydrogen concentration, water levels, temperature and radiation, core-exit temperature, IRWST water level, RCS pressure, and steam generator radiation monitors.

### 19D.6.2 Time Frame 2 - In-Vessel Core Melting and Relocation

Time Frame 2 represents the period of core melting and relocation and the entry into the SAMG. The intact and coolable in-vessel core geometry is lost, and relocation of core debris into the lower head is likely. The in-vessel hydrogen generation and fission product releases from the fuel matrix occur during this time frame.

#### 19D.6.2.1 Injection into the RCS

In Time Frame 2, the in-vessel core configuration loses its coolable geometry and it is likely that at least some of the core debris will migrate to the reactor vessel lower head. If the RCS is depressurized and the reactor vessel is submerged, the core debris will be retained in the reactor vessel. However, injection into the RCS to cover and cool the core debris is required to achieve a controlled, stable state. RCS injection is not required to protect the containment fission product boundary. Injection is successful if it is sufficient to quench the sensible heat from the core debris and refill the reactor vessel. Decay heat removal will then be accomplished by a combination of heat transfer to the water in the reactor vessel and heat transfer to the water on the exterior surface of the reactor vessel.

Severe accident studies for the AP1000 indicate that even with the reactor vessel refilled and the exterior surface of the reactor vessel submerged, the entire core debris may not return to low temperatures (e.g., less than 1200°F for a substantial period of time (e.g., months) if most of the core debris has relocated to the reactor vessel bottom head. This is due to the heat transfer rate through the outer shell of frozen core debris in relation to the heat generation in the central unfrozen core debris. However, this is an extreme case (i.e., no recovery of injection to the RCS until the entire core debris is in the reactor vessel bottom head).

Guidance for establishing RCS injection would be from the AP1000 SAMG (Reference 19D-3). Water can be injected into the RCS using the CVS or the RNS systems. The PXS (CMT, accumulator, IRWST) is not credited in Time Frame 2 in survivability assessments because automatic and manual activation of the system is attempted several times in Time Frame 0 and 1.

Post-core damage, the actions may be monitored with RCS pressure or temperature, containment pressure or CVS or RNS flow rates.

#### 19D.6.2.2 Injection into Containment

The objective of injection to the containment prior to reactor vessel failure (Time Frame 3) is to cool the external surface of the reactor vessel to maintain the core debris in the vessel. Due to the lead time required to submerge the bottom head of the reactor vessel prior to core relocation of the bottom head, injecting to the containment for in-vessel retention is achieved by instructing the operator to drain the IRWST in the EOPs within Time Frame 1.

Since a long lead time is required to submerge the exterior surface of the RPV, the objective of injecting into containment in Time Frame 2 is to provide water in the containment if the accident progresses to RPV failure and Time Frame 3. Two methods are used to inject into containment during Time Frame 2; the containment spray and the addition of water to the IRWST to overflow into containment. There are three methods used to add makeup to the IRWST to overflow; RNS pumps, makeup pumps, and spent fuel system pumps. Draining the IRWST to containment is not credited in Time Frame 2 in survivability assessments because activation of the system is attempted several times in Time Frame 1, and diverse systems are credited to provide reasonable assurance of containment injection survivability in this time frame. If the vessel fails, the accident progresses to Time Frame 3.

Post-core damage, the actions may be monitored with containment water level indication or IRWST water level indication if IRWST overfill is used.

### 19D.6.2.3 Decay Heat Removal and Injection into the Steam Generators

In transients and small LOCAs, initiation of PRHR or injection into the steam generators is required to be recovered in Time Frame 1 to be successful. If the secondary side is dry and the RCS is not depressurized, the steam generator tubes can experience creep rupture due to circulation of hot gases when the cladding oxidation begins at the onset of Time Frame 2. Steam generator injection is not required for LOCAs which depressurize the RCS below the secondary system pressure.

Within Time Frame 2, steam generator injection can be utilized in unisolated SGTR sequences to maintain the water level on the secondary side for mitigation of fission product releases. Injecting into the steam generators, along with depressurization of the RCS, is an accident management action to isolate containment or scrub fission products. Failure to inject to the ruptured steam generator in Time Frame 2 can lead to continued breech of the containment fission product boundary and large offsite doses.

Steam generator feed for non-ruptured SGs is not credited in Time Frame 2 because it is attempted several times in Time Frame 0 and Time Frame 1. However, re-initiation of feedwater to the ruptured steam generator is not attempted until the SAMG, which is not used until Time Frame 2. Thus, re-initiation of feedwater is a Time Frame 2 activity.

The main feedwater and startup feedwater pumps are used to inject into a pressurized secondary system.

The plant response is monitored with the core-exit temperature, RCS temperature, steam generator water level and steam line pressure.

### 19D.6.2.4 Depressurize RCS

RCS depressurization is required within Time Frame 1 for facilitating in-vessel retention of core debris and for successfully preventing steam generator tube failure in high pressure severe accident sequences. The steam generator tubes or hot leg nozzles may fail due to creep rupture after the onset of rapid oxidation at the beginning of Time Frame 2. RCS depressurization facilitates in-vessel retention of core debris in conjunction with injection into the containment to give time to recover pumped injection sources to the RCS to establish a controlled, stable state. RCS depressurization is provided by instructing the operator to depressurize the system in the EOPs in Time Frame 1.

Three methods are used to depressurize the RCS during Time Frame 2: ADS, auxiliary pressurizer spray, and reactor vessel head vent. ADS and auxiliary pressurizer spray are not credited in Time Frame 2 in survivability assessments because activation of the system is attempted several times in Time Frame 1. Survivability of the reactor vessel head vent is assessed only in Time Frame 2.

#### 19D.6.2.5 Depressurize Steam Generators

Active operation to depressurize a steam generator can be used to cooldown the RCS prior to Time Frame 2. After the onset of core melting and relocation, depressurizing steam generators could threaten steam generator tube integrity. Depressurizing the steam generator in Time Frame 2 does not facilitate the establishment of a controlled, stable state. Depressurization of the steam generators is called for in the EOPs and is appropriate only in Time Frame 1 if the RCS is depressurized in order to minimize the pressure differential across the steam generator tubes.

#### 19D.6.2.6 Containment Heat Removal

Automatic actuation of PCS water occurs in Time Frame 0 or 1. In Time Frame 2, PCS flowrate and level are monitored to determine if additional water is needed to permit continuation of PCS flow. Alternate water sources can be provided by connections to the external PCS water tank which is outside the containment pressure boundary and not subjected to the harsh environment.

In addition to PCS water, a nonsafety-related containment spray system can provide heat removal from containment. The design basis purpose of containment spray is scrubbing fission products and containment spray is actuated on high containment radiation levels. This would most likely occur in Time Frame 2 when the fuel rods are overheated and melting. Manually actuating the containment spray system involves opening an air-operated valve inside the containment and actuating valves and a pump outside the containment. Once open, the active operation of the valve inside the containment is completed.

Post-core damage, the actions may be monitored with PCS flow rate and tank water level, containment water level, and containment pressure.

#### 19D.6.2.7 Containment Isolation

Active operation of containment isolation valves is required in Time Frame 0 or 1 to establish the containment fission product barrier. Therefore, only the survivability of the containment pressure boundary, including penetrations, is required to maintain containment isolation after Time Frame 1.

#### 19D.6.2.8 Hydrogen Control

The operator action to actuate the igniters occurs prior to the hydrogen generation at the onset of Time Frame 2. The igniters need to survive and receive power throughout the hydrogen release to maintain the hydrogen concentration below the lower flammability limit during the hydrogen generation in Time Frame 2.

If containment becomes steam inert in Time Frame 2, the igniters will become ineffective and hydrogen will accumulate in containment. The passive auto-catalytic recombiners (PARs) are also available to control hydrogen in containment and can be effective in a steam inert environment. The PARs are not credited in the design basis for severe accidents because they are passive equipment that cannot be controlled by the operating staff from the control room.

The plant response to the igniter actuation can be monitored by containment hydrogen concentration using the hydrogen monitors or containment atmosphere sampling, which is part of the primary sampling system. The containment pressure response can also be used to indicate hydrogen burning which creates a distinctive pressure global peak, but not continual hydrogen burning by the igniters because the energy release to containment is at a low rate and the containment pressure response cannot be distinguished from other heat generation processes.

#### 19D.6.2.9 Control Fission Product Releases

A nonsafety-related containment spray system is provided in AP1000 to wash aerosol fission products from the containment atmosphere. The spray system is manually actuated from the SAMG which is entered at the onset of Time Frame 2. Operating the spray involves opening an air-operated valve inside the containment and actuating valves and a pump outside the containment. Once open, the active operation of the valve inside the containment is completed.

Post-core damage, this action may be monitored with containment water level.

#### 19D.6.2.10 Accident Monitoring

During the initial core melting and relocation, containment hydrogen and radiation monitors are used for core damage assessment and verification of the hydrogen igniter operation. Steam generator radiation monitoring is used to determine steam generator tube integrity. In the longer term, containment atmosphere sampling can be used to monitor hydrogen and radiation. Containment pressure, temperature, and water level indication and RCS pressure need to be monitored throughout Time Frame 2.

During a severe accident, the instrumentation may be subjected to conditions well beyond its design basis. The SAMG does not automatically eliminate instrumentation based on its design basis in comparison to severe accident conditions. Instead, the AP1000 SAMG relies on all available instrumentation indications and instructs the user to constantly compare instrumentation readings to diverse sources to validate the instrumentation reading. It is also noteworthy that while target values are established for various plant parameters to indicate a controlled stable state, the trends of the parameters being monitored are equally as important in managing the accident. The parameter trends indicate whether strategies are effective and determine if additional strategies need to be considered.

### 19D.6.3 Time Frame 3 - Ex-Vessel Core Relocation

Time Frame 3 represents the phase of the accident after vessel failure. The core debris is in the reactor cavity, and the IRWST water is not injected into the containment.

### 19D.6.3.1 Injection into the RCS

The RCS is failed. Injection to the RCS is no longer needed in Time Frame 3. Note that the AP1000 SAMG considers RCS injection as a means to inject water into the reactor cavity in Time Frame 3.

### 19D.6.3.2 Injection into Containment

Water coverage to the ex-vessel debris bed is passively provided by the containment design to drain water from the RCS via the IRWST. Water condensing on the PCS shell is returned to the reactor cavity after filling the IRWST to the overflow. The addition of water to the IRWST from other sources to overflow into containment is also a method of injecting water into containment. Containment spray can also be used to inject water into containment in Time Frame 3. Draining the IRWST to containment is not credited in Time Frame 3 in survivability assessments because activation of the system is attempted several times in Time Frame 1, and diverse systems are credited to provide reasonable assurance of containment injection survivability in this time frame. Containment spray and overflowing the IRWST are also not credited in Time Frame 3 survivability assessments because these methods are already credited in Time Frame 2.

### 19D.6.3.3 Decay Heat Removal and Injection into the Steam Generators

The RCS is failed. PRHR activation or injection into the steam generators is no longer needed in Time Frame 3. Injection to the steam generator for SGTR fission product scrubbing is not required to maintain the water level.

### 19D.6.3.4 Depressurize RCS

The RCS is depressurized by the vessel failure in Time Frame 3.

### 19D.6.3.5 Depressurize Steam Generators

The RCS is failed. Steam generator depressurization is not needed in Time Frame 3.

### 19D.6.3.6 Containment Heat Removal

Active initiation of PCS water is completed prior to Time Frame 3. PCS flowrate and level are monitored for post-72 hour activities. Alternate water sources can be provided by connections to the external PCS water tank which is outside the containment pressure boundary and not subjected to the harsh environment.

In addition to PCS water, a nonsafety-related containment spray system can provide heat removal from containment. The design basis purpose of containment spray is scrubbing fission products and containment spray is actuated on high containment radiation levels. This would most likely occur in Time Frame 2 when the fuel rods are overheated and melting. Manually actuating the containment spray system involves opening an air-operated valve inside the containment and actuating valves and a pump outside the containment. Once open, the active operation of the valve inside the containment is completed.

Post-core damage, the actions may be monitored with PCS flowrate and tank water level, containment water level and containment pressure.

### 19D.6.3.7 Containment Isolation and Venting

Continued operation of the containment shell as a pressure boundary is needed to maintain containment isolation in Time Frame 3. Containment temperature needs to be monitored because prolonged exposure of organic materials (e.g., equipment and personnel hatch seals) to high temperatures (> 400°F) can degrade the material.

In the event of containment pressurization above design pressure due to core concrete interaction non-condensable gas generation, the containment can be vented. Venting protects containment isolation by preventing an uncontrolled containment failure airborne release pathway. The vent can be opened and closed as required to maintain pressure in the containment below its failure pressure. Containment venting does not prevent or mitigate containment basemat failure due to core concrete interaction. Containment venting to the spent fuel pool is available through RNS hot leg suction line MOVs.

### 19D.6.3.8 Combustible Gas Control

The hydrogen igniters are used to control combustible gases. Active operation of igniters continues to control the release of combustible gases (e.g., hydrogen and carbon monoxide) from the degradation of concrete in the reactor cavity.

If containment becomes steam inert in Time Frame 3, the igniters will become ineffective and hydrogen will accumulate in containment. The passive auto-catalytic recombiners (PARs) are also available to control hydrogen in containment and can be effective in a steam inert environment. The PARs are not credited in the design basis for severe accidents because they are passive equipment that cannot be controlled by the operating staff from the control room.

The plant response to the igniter actuation can be monitored by containment hydrogen concentration using the containment atmosphere sampling, which is part of the primary sampling system. The containment pressure response can also be used to indicate hydrogen burning which creates a distinctive pressure global peak, but not continual hydrogen burning by the igniters because the energy release to containment is at a low rate and the containment pressure response cannot be distinguished from other heat generation processes.

### 19D.6.3.9 Control Fission Product Releases

The nonsafety-related sprays are actuated in Time Frame 2. The operation of the nonsafety-related containment spray continues, possibly into Time Frame 3, until the water from the source tank is depleted.

Post-core damage, this action may be monitored with containment water level.

#### 19D.6.3.10 Accident Monitoring

Containment pressure, temperature, water level and radiation, steam generator radiation and the containment hydrogen concentration are sufficient to monitor the accident in the long-term. Hydrogen concentration and radiation can be monitored with containment sampling functions. In both Time Frame 2 and Time Frame 3, auxiliary building radiation monitors, if properly correlated, could be used for containment radiation monitoring.

### 19D.6.4 Summary of Equipment and Instrumentation

The equipment and instrumentation used in achieving a controlled, stable state following a severe accident, and the time it operates are summarized in Tables 19D-3 through 19D-5.

## 19D.7 Severe Accident Environments

The design certification of the AP1000 included consideration by the NRC of the topic referred to in this section.

## 19D.8 Assessment of Equipment Survivability

Since severe accidents are very low probability events, the NRC recommends in SECY-93-087, that equipment desired to be available following a severe accident need not be subject to the qualification requirements of 10CFR50.49, the quality assurance requirements of 10CFR50 Appendix B, or the redundancy/diversity requirements of 10CFR50 Appendix A. It is satisfactory to provide reasonable assurance that the designated equipment will operate following a severe accident by comparing the AP1000 severe accident environments to design basis event/severe accident testing or by design practices.

### 19D.8.1 Approach to Equipment Survivability

The approach to survivability is by equipment type, equipment location, survival time required, and the use of design basis event qualification requirements and severe environment experimental data.

#### 19D.8.1.1 Equipment Type

The various types of equipment needed to perform the activities discussed above are transmitters, thermocouples, resistance temperature detectors (RTDs), hydrogen and radiation monitors, valves, pumps, valve limit switches, containment penetration assemblies, igniters, and cables.

#### 19D.8.1.2 Equipment Location

Some of the in-containment equipment, such as transmitters, has been deliberately located to avoid the most severe calculated environments. Other equipment is located outside containment. The performance of the equipment was judged based on the most severe postulated event for that location.

### 19D.8.1.3 Time Duration Required

Requirements are defined for each time frame, so the equipment evaluation only discusses performance during these periods. A limited amount of equipment has been designated for the long term (Time Frame 3) and these parameters can be monitored outside containment.

### 19D.8.1.4 Severe Environment Experiments

The primary source for performance expectations of similar equipment in severe accident environments is EPRI NP-4354, "Large Scale Hydrogen Burn Equipment Experiments." This information is supplemented by NUREG/CR-5334, "Severe Accident Testing of Electrical Penetration Assemblies." These programs tested equipment types that had previously been qualified for design basis event environmental conditions. The temperature in the chamber for the first program was in the 700°F - 800°F range for ten to twenty minutes during the continuous hydrogen injection tests. Although the conditions at the equipment would be somewhat less severe, the chamber conditions envelop all of the longer duration profiles indicated for the AP1000 events. The equipment in this program was also exposed to significant hydrogen burn spikes that are also postulated for the AP1000 plant. The same equipment was exposed to and survived several events, both pre-mixed and continuous hydrogen injection which provides confidence in its ability to survive a postulated severe accident. The second program tested containment penetrations to high temperatures for long durations. A penetration was tested under severe accident conditions simulated with steam up to 400°F and 75 psia for ten days. The results indicated that the electrical performance of the penetration would not lead to degraded equipment performance for the first four days. The mechanical performance did not degrade (no leaks) during the entire test.

### 19D.8.2 Equipment Located in Containment

The exposure to elevated temperatures as a direct result of the postulated severe accident or as a result of hydrogen burning is the primary parameter of interest. Pressure environments do not exceed the design basis event conditions for which the equipment has been qualified if PCS is operating as designed. Radiation environments also do not exceed the design basis event conditions throughout Time Frames 1 and 2.

### 19D.8.2.1 Differential Pressure and Pressure Transmitters

The functions defined for accident management that utilize in-containment transmitters are IRWST water level, reactor coolant system pressure, steam generator wide range water level, and containment pressure. Most of these transmitters that provide this information are located in rooms where the environment is limited to short duration temperature transients. These transients exceed ambient design basis temperature conditions but should not impact the transmitter performance since the internal transmitter temperature do not increase significantly above that experienced during design basis testing. EPRI NP-4354 documents transmitter performance during several temperature transients with acceptable results. The IRWST water level transmitters are located in the maintenance floor and are only required during Time Frames 1 and 2. The environment during Time Frames 1 and 2 does not exceed the design basis qualification parameters of the transmitters if PCS is operating as designed. Reactor system pressure and steam generator wide range water level are required through the second time frame. The only long term application is the containment pressure transmitter which may eventually be impacted by the severe accident radiation dose.

#### 19D.8.2.2 Thermocouples

The functions defined for severe accident management that utilize thermocouples are core-exit temperatureand containment water level. The core-exit temperature is only required during Time Frame 1 and the containment water level is required through Time Frame 2. The temperatures to which the thermocouples are exposed during the defined time frames do not exceed the thermocouple design.

#### 19D.8.2.3 Resistance Temperature Detectors (RTDs)

Both hot and cold leg temperatures are defined as parameters for severe accident management in Time Frame 1. RTDs are utilized for these measurements and will perform until their temperature range is exceeded. The hot leg RTDs could fail as the temperature increases well above the design conditions of the RTDs but the cold leg RTDs should perform throughout Time Frame 1. RTDs are also utilized through Time Frame 3 for the containment temperature measurement and are exposed to temperature transients that exceed design basis qualification conditions. EPRI NP-4354 documents RTD performance during several temperature transients with acceptable results.

#### 19D.8.2.4 Hydrogen Monitors

Containment hydrogen is defined as a parameter to be monitored throughout the severe accident scenarios. Early in the accident, the hydrogen may be monitored by a device that operates on the basis of catalytic oxidation of hydrogen on a heated element. The hydrogen monitors are located in the main containment area. The design limits of this device may be exceeded after the first few hours of some of the postulated accidents and performance may be uncertain. If the device fails, post-accident sampling of containment atmosphere using analysis of grab samples may be used to determine containment hydrogen concentrations.

#### 19D.8.2.5 Radiation Monitors

Containment radiation is defined as a parameter to be monitored throughout the severe accident scenarios. The containment radiation monitors are located in the main containment area. Early in the accident, the design basis event qualified containment radiation monitor provides the necessary information until the environment exceeds the design limits of the monitor. If the device fails, containment radiation is determined through the containment atmosphere sampling function or by portable monitors located against the outside of the containment shell.

#### 19D.8.2.6 Solenoid Valve

Qualified solenoid valves are used to vent air-operated valves (AOVs) to perform the function required. In Time Frame 1, the core makeup tank AOVs located in the accumulator room provide a path for RCS injection, the PRHR AOVs located in the maintenance floor provide a path for RCS heat removal and the containment is isolated by AOVs located in the maintenance floor and the PXS valve/accumulator room. The environment to which these solenoid valves may be exposed in Time Frame 1 is not significantly different than the design basis events to which the devices are qualified. In Time Frame 2, the RCS boundary AOV located in the maintenance floor is used for CVS injection into the RCS and the containment spray AOV located in the maintenance floor is used for control of fission product release. Also in Time Frame 2, the reactor vessel head vent AOVs provide a path for RCS depressurization. In addition, throughout Time Frame 3, access to the containment environment from the containment atmosphere sampling function is through solenoid valves located in the maintenance floor. During Time Frame 2 and Time Frame 3, these valves may be exposed to transient conditions due to hydrogen burns that exceed design basis event qualification. Solenoid valves in an energized condition were included in the hydrogen burn experiments (EPRI NP-4354) and survived many transients. Shielding provided by the location of the valves limits the severe accident radiation dose to the typical design basis qualification dose for these valves.

### 19D.8.2.7 Motor-Operated Valves

Motor-operated valves (MOVs) are utilized in several applications during the severe accident scenarios. MOVs in the accumulator and core makeup tank path are normally open and remain open. In Time Frame 1, the PXS recirculation MOVs located in the PXS valve/accumulator room are required for injection of water into the containment, MOVs for the first three stages of ADS located in a compartment above the pressurizer are required for RCS depressurization and the containment is isolated by MOVs located in the maintenance floor and the PXS valve/accumulator room. The environment to which these MOVs may be exposed in Time Frame 1 is not significantly different than the design basis events to which they are qualified. In Time Frame 2, the charging and injection MOV located in the maintenance floor provides a path from the CVS for RCS injection and an RNS MOV located in the PXS valve/accumulator room provides a path from the IRWST for RCS injection. In addition, throughout Time Frame 3, containment venting to the spent fuel pool is available through RNS hot leg suction line MOVs located in the RNS valve room. During Time Frames 2 and 3, these valves may be exposed to transient conditions due to hydrogen burns that exceed design basis event qualification. MOVs were included in the hydrogen burn experiments (EPRI NP-4354) and survived many transients. Shielding provided by the location of the valve limits the severe accident radiation dose to the typical design basis qualification dose for these valves.

### 19D.8.2.8 Squib Valves

Squib valves are only required in Time Frame 1 when the severe accident environment is not significantly different than the design basis environment for which these valves are qualified. IRWST and PXS recirculation squib valves located in the accumulator room are used for injection into the RCS and containment, respectively. For RCS depressurization, the fourth stage ADS squib valves are located in steam generator compartments 1 and 2.

### 19D.8.2.9 Position Sensors

Position sensors are required to monitor the position of containment isolation valves that could lead directly to an atmospheric release. These isolation valves actuate early in the transient, so verification is only required during Time Frame 1. The position sensors are located in the maintenance floor and the environment in this time frame does not exceed the design basis event qualification environment of the position sensors.

### 19D.8.2.10 Hydrogen Igniters

The hydrogen igniters are distributed throughout the containment and are designed to perform in environments similar to those postulated for severe accidents. The igniters' transformers are located outside containment. The successful results of glow plug testing through several hydrogen burns is documented in EPRI NP-4354 and provides confidence in the performance of these devices.

### 19D.8.2.11 Electrical Containment Penetration Assemblies

The electrical containment penetrations are located in the lower compartment and are required to perform both electrically and mechanically throughout the severe accident. The hydrogen burn equipment experiments documented by EPRI NP-4354 included penetrations qualified for nuclear plants. Electrical testing on the penetration cables after all the pre-mixed and continuous injection tests concluded that most of the cables passed the electrical tests while submerged in water. These tests consisted of ac (at rated voltage) and dc (at three times rated voltage) withstand tests and insulation resistance tests at 500 volts. The penetrations were also tested under simulated severe accident conditions at 400°F and 75 psia for about 10 days (NUREG/CR-5334). The results indicated that some degradation in instrumentation connected to the penetration may occur in four days under these severe conditions. The maintenance floor may experience short temperature transients above 400°F but stable temperatures are significantly less, so it is expected that the electrical performance would be maintained throughout the event. The only long term measurement utilizing these penetrations is containment pressure and this can be measured outside containment if necessary. There was no degradation of mechanical performance of the electrical penetrations (maintaining the seal) in either test program.

### 19D.8.2.12 Cables

The hydrogen burn equipment experiments documented by EPRI NP-4354 included twenty-four different cable types qualified for nuclear plants. Electrical testing on these cables after all the pre-mixed and continuous injection tests concluded that all (fifty two samples) of the cables passed the electrical tests while submerged. These tests consisted of ac (at rated voltage) and dc (at three times rated voltage) withstand tests and insulation resistance tests at 500 volts. Due to the exposure to many events, some cable samples had extensive damage in the form of charring, cracking and bulging of the outer jackets and still performed satisfactorily. The cables tested are representative of cables specified for the AP1000 and are only exposed to short single temperature transients in their respective locations. Proper performance can be expected. The only long term measurement utilizing cables is containment pressure, which can be measured outside containment if necessary.

### 19D.8.2.13 Assessment of Equipment for Sustained Burning

The equipment necessary for equipment survivability in sustained burning environments is defined in Tables 19D-3 through 19D-5. The equipment in Table 19D-3 includes equipment and instrumentation operation during Time Frame 1 - core uncovery and heatup, and is prior to the release of significant quantities of hydrogen. Therefore, it does not have to be qualified for sustained hydrogen burning. Table 19D-7 specifies the equipment and instrumentation used in Time Frames 2 and 3 to provide reasonable assurance of achieving a controlled stable state.

### 19D.8.3 Equipment Located Outside Containment

Other functions defined for severe accident management are performed outside containment and the equipment is not subjected to the harsh environment of the event. This equipment includes, but is not limited to:

- Steam line radiation monitor,
- Transmitters for monitoring steam line pressure,
- Passive containment cooling system flow and tank level,
- Containment atmosphere sampling function,
- Makeup pumps and flow measurement,
- RNS pumps and flow measurement,
- SFS pumps and flow measurement,
- RNS MOVs
- MFW pumps and valves,
- SFW pumps and valves,
- Steam generator PORVs and main steam bypass valves for depressurization,
- Recirculation pumps, PCS valves and fire water pumps and valves for containment heat removal,
- Containment isolation valves (outside containment),
- Auxiliary building radiation monitor,
- MOV and manual valve from RNS hot leg suction lines to the spent fuel pool and
- Fire water, fire pumps, valves and flow measurement used to provide containment spray and backup containment cooling.

## 19D.9 Conclusions of Equipment Survivability Assessment

The equipment defined for severe accident management was reviewed for performance during the environments postulated for these events. Survivability of the equipment was evaluated based on design basis event qualification testing, severe accident testing, and the survival time required following the initiation of the severe accident. The equipment that is qualified for design basis events has a high probability of surviving postulated severe accident events and performing satisfactorily for the time required.

This assessment provides reasonable assurance that equipment, both electrical and mechanical, used to mitigate the consequences of severe accidents and achieve a controlled, stable state can perform over the time span for which they are needed.

## 19D.10 References

19D-1 APP-GW-GL-027, “Framework for AP1000 Severe Accident Management Guidance,” Westinghouse Electric Company LLC.

19D-2 AP1000 Emergency Operating Procedures.

19D-3 APP-GW-GJR-400, "AP1000 Severe Accident Management Guidelines," Westinghouse Electric Company LLC.

Table 19D-1

**DEFINITION OF EQUIPMENT SURVIVABILITY TIME FRAMES**

| Time Frame | Beginning Time | Ending Time | Comments |
|---|---|---|---|
| 0 | Accident initiation | safe, stable state<br>or<br>core uncovery | • Bounded by design basis equipment qualification environment |
| 1 | Core uncovery | controlled, stable state<br>or<br>rapid cladding oxidation | • Core uncovery and heatup<br>• Bounded by design basis equipment qualification environment |
| 2 | Rapid cladding oxidation | controlled, stable state<br>or<br>vessel failure | • In-vessel core melting and relocation<br>• Entry into SAMG |
| 3 | Vessel failure | controlled, stable state<br>or<br>containment failure | • Ex-vessel core relocation |

Table 19D-2

**AP1000 HIGH LEVEL ACTIONS RELATIVE TO ACCIDENT MANAGEMENT GOALS**

| Goal | Element | High Level Action* |
|---|---|---|
| Controlled, stable core | water inventory in RCS | • inject into RCS<br>• depressurize RCS |
| | water inventory in containment | • inject into containment |
| | heat transfer to IRWST | • initiate PRHR |
| | heat transfer to SGs | • inject into RCS<br>• inject into SGs |
| | heat transfer to containment | • inject into RCS<br>• inject into containment<br>• depressurize RCS<br>• initiate PRHR |
| Controlled, stable containment | heat transfer from containment | • depressurize containment<br>• vent containment<br>• water on outside containment |
| | isolation of containment | • inject into SGs<br>• depressurize RCS |
| | hydrogen prevention/control | • burn hydrogen<br>• pressurize containment<br>• depressurize RCS<br>• inject into containment<br>• vent containment<br>• water on outside containment |
| | core concrete interaction prevention | • inject into containment |
| | high pressure melt ejection prevention | • inject into containment<br>• depressurize RCS |
| | creep rupture prevention | • depressurize RCS<br>• inject into SGs |
| | containment vacuum prevention | • pressurize containment |
| Terminate fission product release | isolation of containment | • inject into SGs<br>• depressurize RCS |
| | reduce fission product inventory | • inject into containment<br>• depressurize RCS |
| | reduce fission product driving force | • depressurize containment<br>• water on outside containment |

**Note:**

* See Tables 19D-3, 19D-4 and 19D-5

Table 19D-3 (Sheet 1 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION PRIOR TO END OF TIME FRAME 1 - CORE UNCOVERY AND HEATUP**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Inject into RCS | • CMT<br>• accumulator<br>• IRWST<br>• CVS<br>• RNS | • core-exit t/c's<br>• RCS pressure<br>• RCS RTDs<br>• CVS flow<br>• RNS flow<br>• IRWST water level | • restore core cooling | • injection must often be recovered to be successful in severe accident |
| Inject to SGs | • MFW<br>• SFW | • SG WR water level<br>• steam line pressure | • decay heat removal<br>• make SGs available to depressurize RCS<br>• prevent SG tube creep rupture | • injection source must often be recovered to be successful in severe accident |
| Decay Heat Removal | • PRHR Hx<br>• via SGs | • IRWST water level<br>• IRWST temperature<br>• core-exit t/c's<br>• RCS RTDs | • decay heat removal | • only works if RCS is reflooded and IRWST water level covers PRHR Hx |
| Depressurize RCS | • ADS<br>• aux pressurizer spray<br>• via SGs<br>• PRHR Hx | • RCS pressure<br>• IRWST water level<br>• IRWST temperature<br>• steam line pressure | • facilitate injection to RCS<br>• long term heat transfer path | • ADS often automatic |
| | | | • prevent SG tube creep rupture<br>• containment integrity | • RCS depressurization required prior to significant cladding oxidation to prevent creep rupture |
| | | | • isolate break in SGTR | • uses intact SG or PRHR |
| | | | • prevent vessel failure | • requires injection to containment to be successful |

Table 19D-3 (Sheet 2 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION PRIOR TO END OF TIME FRAME 1 - CORE UNCOVERY AND HEATUP**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Depressurize SGs | • SG PORV<br>• main steam bypass | • steam line pressure<br>• RCS pressure<br>• SG WR water level | • depressurize RCS<br>• minimize pressure differential across SG tubes | • requires injection into SGs to prevent creep rupture |
| Inject Into Containment | • IRWST drains | • core-exit t/c's<br>• containment water level<br>• IRWST water level | • prevent vessel failure | • manual cavity flooding action in EOP |
| Containment Isolation | • containment isolation system<br>• containment shell<br>• penetrations | • containment isolation system valve position<br>• containment pressure | • containment integrity | • containment isolation system often automatic<br>• manual action in EOP |
| Control Hydrogen | • igniter | • containment hydrogen monitors<br>• containment atmosphere sampling functions<br>• containment pressure | • containment integrity | • manual igniter action in EOP |
| Containment Heat Removal | • PCS water<br>• external water | • containment pressure<br>• PCS flowrate<br>• PCS tank level | • containment integrity<br>• alleviate environmental challenge to equipment<br>• long term heat transfer path | • PCS water automatic |

Table 19D-3 (Sheet 3 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION PRIOR TO END OF TIME FRAME 1 - CORE UNCOVERY AND HEATUP**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Accident Monitoring | | • SG radiation<br>• containment pressure<br>• containment temperature<br>• containment hydrogen monitors<br>• containment water level<br>• containment radiation<br>• containment atmosphere sampling functions<br>• auxiliary building radiation<br>• core-exit t/c's<br>• RCS pressure<br>• IRWST water level | • accident management<br>• emergency response(1)<br>• emergency action levels(1) | • required by 10 CFR 50.34(f) |

**Note:**

1. Note that the instrumentation required for emergency response and emergency action levels is an open item because the EALs are not yet developed.

Table 19D-4 (Sheet 1 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION DURING TIME FRAME 2 - IN-VESSEL CORE MELTING AND RELOCATION**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Inject into RCS | • CMT<br>• accumulator<br>• IRWST<br>• CVS<br>• RNS | • RCS pressure<br>• containment pressure<br>• CVS flow<br>• RNS flow<br>• RCS temperature | • cool core debris in-vessel | • RCS injection needed to cool in-vessel debris for reasonable assurance of controlled, stable state |
| Decay Heat Removal | • via SGs | • SG WR water level<br>• steam line pressure<br>• core-exit t/c's<br>• RCS RTDs | • decay heat removal | |
| Inject Into Containment | • containment spray<br>• overflow IRWST<br>• RNS<br>• IRWST drains | • containment water level | • prevent vessel failure | • containment spray only actuated on high containment radiation in SAMG which occurs in Time Frame 2 |
| Inject to SGs | • MFW<br>• SFW | • SG WR water level<br>• steam line pressure | • isolate containment in SGTR<br>• scrub fission products | • also requires RCS depressurization for containment isolation |
| Depressurize RCS | • ADS<br>• aux pressurizer spray<br>• reactor vessel head vent | • RCS Pressure | • prevent vessel failure<br>• containment integrity | • needed for in-vessel retention of core debris<br>• needed for prevention of TI-SGTR<br>• try to recover in Time Frame 2, if not successful in Time Frame 1 |

Table 19D-4 (Sheet 2 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION DURING TIME FRAME 2 - IN-VESSEL CORE MELTING AND RELOCATION**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Depressurize SGs | | | | • not needed in Time Frame 2 |
| Containment Heat Removal | • PCS water<br>• external water<br>• containment spray | • PCS flowrate<br>• PCS tank level<br>• containment water level<br>• containment pressure | • containment integrity | • active operation completed in Time Frame 1; needs to be continued in Time Frame 2 |
| Containment Isolation | • containment shell<br>• penetrations | • containment pressure | • containment integrity | • containment isolation system active operation completed in Time Frame 1 |
| Control Hydrogen | • igniters | • containment hydrogen monitors<br>• containment atmosphere sampling function<br>• containment pressure | • containment integrity | • active operation continues in Time Frame 2<br>• monitors only required initially to verify hydrogen igniter operation |
| Control Fission Product Releases | • containment spray | • containment water level | • scrub fission products | • containment spray only actuated on high containment radiation in SAMG which occurs in Time Frame 2 |

Table 19D-4 (Sheet 3 of 3)

**EQUIPMENT AND INSTRUMENTATION OPERATION DURING TIME FRAME 2 - IN-VESSEL CORE MELTING AND RELOCATION**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Accident Monitoring | | • SG radiation<br>• containment pressure<br>• containment temperature<br>• containment hydrogen monitors<br>• containment water level<br>• containment radiation<br>• containment atmosphere sampling functions<br>• auxiliary building radiation<br>• RCS pressure | • accident management<br>• emergency response(1)<br>• emergency action levels(1) | • active operation continues in Time Frame 2 |

**Note:**

1. Note that the instrumentation required for emergency response and emergency action levels is an open item because the EALs are not yet developed.

Table 19D-5 (Sheet 1 of 2)

**EQUIPMENT AND INSTRUMENTATION OPERATION DURING TIME FRAME 3 - EX-VESSEL CORE RELOCATION**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Inject into RCS | | | | • not needed in Time Frame 3 |
| Decay heat removal | | | | • not needed in Time Frame 3 |
| Inject into SGs | | | | • not needed in Time Frame 3 |
| Depressurize RCS | | | | • not needed in Time Frame 3 |
| Depressurize SGs | | | | • not needed in Time Frame 3 |
| Inject Into Containment | • Containment spray<br>• Overflow IRWST<br>- CVS<br>- RNS<br>- SFS<br>• IRWST drains | • containment water level | • cool ex-vessel core debris to prevent or mitigate consequences of CCI<br>• scrub fission products released from ex-vessel core debris | • only get to Time Frame 3 if there is no water in containment or if RCS depressurization fails |
| Containment Heat Removal | • PCS water<br>• external water<br>• containment spray | • PCS flowrate<br>• PCS tank level<br>• containment water level<br>• containment pressure | • containment integrity | • active operation completed in Time Frame 1; needs to be continued in Time Frame 3 |
| Containment Isolation | • containment shell<br>• penetrations | • containment pressure<br>• containment temperature | • containment integrity | • active operation of containment isolation system completed in Time Frame 1 |
| | • RNS hot leg suction MOVs | • containment pressures<br>• SFP water level | • containment vent | • manual action within SAMG |
| Control Hydrogen | • igniters | • containment atmosphere sampling function<br>• containment pressure | • containment integrity | • active operation continues in Time Frame 3<br>• PARS may be effective in Time Frame 3 if igniters are not effective |

Table 19D-5 (Sheet 2 of 2)

**EQUIPMENT AND INSTRUMENTATION OPERATION DURING TIME FRAME 3 - EX-VESSEL CORE RELOCATION**

| Action | Equipment | Instrumentation | Purpose | Comment |
|---|---|---|---|---|
| Control Fission Product Release | • containment spray | • containment water level | • scrub fission products | • containment spay only actuated on high containment radiation in SAMG which occurs in Time Frame 3 |
| Accident Monitoring | | • SG radiation<br>• containment pressure<br>• containment temperature<br>• containment hydrogen monitors<br>• containment water level<br>• containment radiation<br>• containment atmosphere sampling function<br>• auxiliary building radiation monitors | • accident management<br>• emergency response(1)<br>• emergency action levels(1) | • active operation continues in Time Frame 3 |

**Note:**
1. The instrumentation required for emergency response and emergency action levels is an open item because the EALs are not yet developed.

| |
|---|
| TABLE 19D-6 NOT USED. |

Table 19D-7 (Sheet 1 of 3)

**SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT**

| EQUIPMENT AND INSTRUMENTATION | SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT |
|---|---|
| **Equipment** | |
| PXS equipment (injection) | The PXS equipment utilized for introduction of cooling water includes component redundancy and is separated into two delivery flow paths. The two flow paths are physically separated into two trains such that if one train is disabled due to a sustained burn from DVI or other line break within that subsystem, the other subsystem will function. |
| CVS equipment (injection) | The equipment providing for CVS injection is located within the CVS compartment with the exception of the CVS makeup isolation valve. In accordance with the above, a sustained burn will not occur within the CVS compartment and, therefore, the equipment within this compartment utilized for CVS makeup will be operable. The CVS makeup isolation valve is normally in the correct position for severe accident scenario and is considered operable. |
| RNS equipment (injection) | Injection via the RNS is dependent only upon check valves within containment and, therefore, is not susceptible to sustained burning effects. |
| Main Feedwater | The operability of main feedwater system to inject feedwater to steam generators is not dependent upon equipment located within containment and, therefore, is not susceptible to sustained burning effects. |
| Startup Feedwater | The operability of startup feedwater system to inject feedwater to steam generators is not dependent upon equipment located within containment and, therefore, is not susceptible to sustained burning effects. |
| Fire Water, containment spray, and external containment vessel cooling | The operability of the fire water system to provide makeup for containment spray and for external containment vessel cooling is not dependent upon equipment located within containment and, therefore, is not susceptible to sustained burning effects. |

Table 19D-7 (Sheet 2 of 3)

**SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT**

| EQUIPMENT AND INSTRUMENTATION | SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT |
|---|---|
| **Equipment** | |
| Containment Shell | As discussed in Section 19.41.7 of this document, hydrogen plumes are located away from the containment shell to mitigate the threat to the containment integrity. |
| Igniters | Igniters are specified and designed to withstand the effects of sustained burning and, therefore, are considered operable for these events. |
| **Instrumentation** | |
| RCS Pressure | There are four RCS pressurizer pressure transmitters. Two transmitters are located at a distance greater than 75 feet from the vent from the PXS valve/accumulator room and are therefore beyond the distance that potentially causes operability concerns from a sustained flame. The other two transmitters are located in a different room from the fourth stage ADS valves. This precludes radiative heating, which could potentially cause operability concerns. |
| Containment Pressure | There are three extended range containment pressure transmitters. The three transmitters are located such that they cannot all be exposed to a sustained flame from either of the vents from the PXS valve/accumulator room into the maintenance floor at the base of the CMTs. Therefore, continued operability of the containment pressure function is provided. |
| SG 1 Wide Range Level | There are four steam generator wide range levels for SG 1. Two of the transmitters are located at a distance of greater than 20 feet from a CMT and are, therefore, beyond the distance that could potentially cause operability concerns from a sustained flame from the vent from the PXS valve/accumulator room into the maintenance floor at the base of the CMT. The other two transmitters are located over 20 feet below the fourth stage ADS valves. This precludes radiative heating, which could potentially cause operability concerns. |
| SG 2 Wide Range Level | Based on the layout of the four steam generator wide range levels for SG 2, at least two of the transmitters will not be exposed to a sustained flame from either of the vents from the PXS valve/accumulator room into the maintenance floor at the base of the CMTs. Therefore, continued operability of the SG 2 wide range level indication function is provided. |

Table 19D-7 (Sheet 3 of 3)

**SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT**

| EQUIPMENT AND INSTRUMENTATION | SUSTAINED HYDROGEN COMBUSTION SURVIVABILITY ASSESSMENT |
|---|---|
| **Instrumentation** | |
| Containment Hydrogen Monitors | There are 3 distributed containment hydrogen monitors. There are no sustained burns that could potentially affect the two sensors that are located at an elevation of 164 feet or the sensor located within the dome. |
| Containment Atmosphere Sampling Function | The capabilities to perform containment atmosphere sampling are discussed in Section 9.3.3.1.2.2 – Post-Accident Sampling. Successful containment atmosphere sampling is dependent on the availability of either of the hot leg sample source isolation valves and the containment isolation valves in series with the isolation valve. The sample isolation valve from reactor coolant hot leg number 1 is located in a different room from the fourth stage ADS valves. This precludes radiative heating, which could potentially cause operability concerns. The sample isolation valve from reactor coolant hot leg number 2 is located in a different room from the fourth stage ADS valves. This precludes radiative heating, which could potentially cause operability concerns. The containment isolation valves are located less than 20 feet from a CMT. However, a steel shroud around base of the CMT prevents a sustained flame existing on the containment side of that CMT and, therefore, affecting the operability of either of the containment isolation valves. |